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(54) Spread spectrum receiver with reduction of intersymbol interference

(57) A receiver for recovering data from received spread spectrum radio signals, the receiver comprising an equaliser means (22), which operates to mitigate at least some inter symbol interference present in the sampled base band signals (22, 28) and to condition the remaining inter symbol interference to the effect that said radio signals received via at least one propagation path are present in said conditioned remaining signals, and a symbol estimation means (26, 30, 32, 34) coupled to the equaliser means (22, 28) and arranged to estimate the data by de-spreading the spread spectrum radio signals corresponding to said at least one path, with respect to a corresponding spreading code consequent upon said conditioned remaining signals (22, 28).

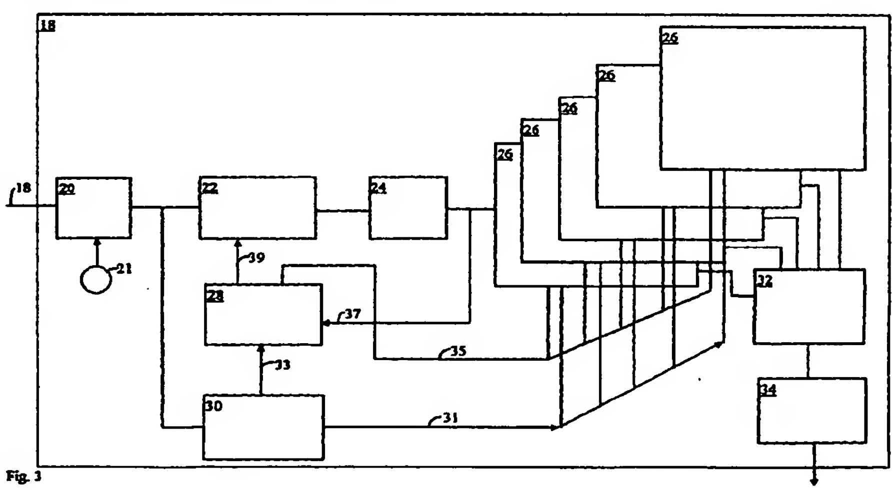

Fig. 3

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Description

[0001] The present invention relates to receivers for recovering data from spread spectrum radio signals. Furthermore the present invention relates to methods of recovering data from spread spectrum radio signals.

[0002] Data is communicated using spread spectrum radio signals by combining the data with a spreading code which has an effect of increasing the bandwidth of the radio signals on to which the data and spreading code combination are modulated. Properties of the spreading code facilitate detection of the radio signals and recovery of the data at a receiver, in spite of the presence of contemporaneously detected like modulated spread spectrum radio signals generated by other transmitters. As a result, spread spectrum radio systems are used in mobile radio telephone systems to provide contemporaneous communication of data from a plurality of mobile stations. This is known as code division multiple access, and has been selected for both second and third generation mobile radio communication systems.

[0003] A characteristic of radio communications within a part of the radio frequency spectrum allocated to mobile radio communication systems, is that the radio signals propagate from transmitters to receivers via a plurality of paths. As a result, the radio signals detected by the receiver are superimposed. Where a temporal difference in the propagation time between at least two paths differs by more than a symbol period, inter-symbol interference results which must be mitigated in the receiver in order for data communicated by the radio signals to be recovered.

[0004] A known receiver which operates to recover data from received spread spectrum radio signals is known to those skilled in the art as a rake receiver. The rake receiver is known to be provided with a plurality of rake fingers. Each of the rake fingers is assigned on a pre-determined basis to one of a plurality of delays corresponding to the relative propagation delay experienced by the radio signals travelling via propagation paths along which the received radio signals may have travelled between the transmitter and the receiver. Thus the rake fingers are positioned temporarily with respect to each other and within each rake a cross-correlator is arranged to cross-correlate the received radio signals with a locally generated version of the user specific spreading code. The cross-correlation after a symbol period, generated by each of the rake fingers, is thereafter combined in order to generate an estimate of the data symbols communicated by the radio signals.

[0005] A disadvantage with known rake receivers is that substantial parts of the energy of the radio signals may reach the receiver via paths which have a propagation delay corresponding to a relative temporal displacement falling between the temporal position of the fingers of the rake receiver. As such self-interference occurs within the rake receiver in that the energy corresponding to paths not in correspondence with the temporal position of the rake fingers causes interference with the correlation of the received radio signals within the rake fingers. Additionally each path received by a finger even produces self interference to all other fingers. The self-interference is governed approximately by the auto-correlation function of segments of the spreading code.

[0006] Another known disadvantage of the rake receiver is caused by what is known as the 'near/far' problem. The 'near/far' problem is known to those skilled in the art as an effect whereby radio signals transmitted by a transmitter close to the receiver, having a relatively strong received signal strength, have an effect of suppressing radio signals transmitted by a transmitter further away, having a relatively weak signal strength. This has an effect of further exacerbating self-interference, especially where several paths of approximately the same amplitude which are not in synchronisation with the corresponding temporal position of the rake fingers are present in the received signals.

[0007] As already explained, a spread spectrum radio signal is generated by combining the data symbols to be communicated with a spreading code and modulating the resulting combination onto a radio frequency carrier signal. The spreading code typically comprises a plurality of symbols known as chips which are combined with the data by modulating the spreading code with the data in some way. Furthermore, in order to provide appropriate spectral shaping, the chips of the spreading code are combined with a modulation filter such as, for example, a root raised cosine filter. A root raised cosine modulation filter is well known to those skilled in the art, and it is known that by passing the received signal through a receiver filter having a corresponding root raised cosine filter, a raised cosine pulse shape results, with an effect that if the signal is sampled at the symbol rate or in this case the chip rate, then no inter symbol interference is present in the received signal samples. This is, of course, under the condition that there is no inter-symbol interference caused by the channel.

[0008] As already explained, multi-path propagation is a characteristic of radio communications in a frequency band used by mobile radio communication systems. As a result, inter-symbol interference resulting from the transmit and receive filters will be present at each of the correlators of the rake fingers, as a result of paths causing self interference. In other words, the self interference problem has a further effect that the received chips are superimposed, causing residual inter-symbol interference in the received signal. In order to prevent non-linear distortions by aliasing when decimating the signal to the chip rate a very high initial sample rate is required so as to allow a fine time resolution of the decimation process. In order to effect this time resolution, the received signal must be over sampled at the chip rate. However, since the chip rate is already many times greater than the symbol rate, over sampling at the chip rate is undesirable.

[0009] It is an object of the present invention to provide a receiver for recovering data from received spread spectrum radio signals in which inter symbol interference is substantially reduced, without a requirement for sampling the spread spectrum signal at a high rate.

[0010] The present invention may be described generally by providing an adaptive pre-equaliser to pre-process the received spread spectrum signal before a rake detector. The pre-equaliser reduces an amount of inter symbol interference resulting from a number of strong propagation paths, to the effect that residual inter-symbol interference at the output of the pre-equaliser may be substantially mitigated by the rake detector, thereby facilitating detection and recovery of the data using the rake receiver. Any type of pre-equaliser such as a linear equaliser or a decision feedback equaliser may be used.

[0011] According to the present invention there is provided a receiver in accordance with patent claim 1.

[0012] By providing a pre-equaliser before the rake detector, some and ideally all of the inter-symbol interference may be cancelled in the received spread spectrum radio signals, and any remaining inter-symbol interference cancelled by the rake detector.

[0013] The equaliser may operate to condition the remaining inter-symbol interference to the effect that the remaining inter-symbol interference corresponds to paths at temporal positions corresponding to the temporal position of the rake fingers.

[0014] The equaliser means may operate to convolve the received signals with a plurality of equaliser coefficients. The receiver may further include a data processor which operates to adapt the equaliser coefficients to the effect of minimising an error signal derived from the received signals.

[0015] The receiver may be a linear equaliser or a decision feedback equaliser.

[0016] Linear equalisers and digital feedback equalisers are known to suffer error propagation and noise enhancement if arranged to cancel all inter-symbol interference in a received signal. However the present invention offers an advantage in that by only mitigating part of the inter-symbol interference in the received signal, the equaliser may operate according to a linear or a decision feedback equaliser whilst not incurring the disadvantage of noise enhancement or error propagation.

[0017] The equaliser means offers a further advantage in that chip timing synchronisation is substantially achieved by the equaliser means which acts as an interpolation filter adjusting the delays for the subsequent rake detector. Furthermore synchronisation may be achieved not only to the chip rate but also to the symbol rate, therefore obviating a requirement to acquire symbol synchronisation after the received spread spectrum radio signals have been de-spread.

[0018] As will be appreciated the present invention can operate with an equaliser means having fractional spaced equaliser taps or T or chip spaced equaliser taps.

[0019] According to an aspect of the present invention there is provided a method of recovering data from received spread spectrum radio signals according to patent claim 1a.

[0020] One embodiment of the present invention will now be described by way of example only with reference to the accompanying drawings wherein;

FIGURE 1 is a schematic block diagram of a mobile radio telecommunication system;

FIGURE 2 is a schematic illustration of the propagation of radio signals from the mobile stations shown in Figure 1 to a one of the base stations shown in Figure 1;

FIGURE 3 is a schematic block diagram of a data detector which operates to recover data from received spread spectrum radio signals; and

FIGURE 4 is a schematic block diagram of a receiver controller shown in Figure 3.

[0021] The example embodiment of the present invention will be illustrated with reference to a mobile radio telecommunication system and in particular to a mobile radio telecommunication system which operates in accordance with code division multiple access (CDMA).

[0022] An illustrative example of a mobile radio telecommunication system is provided in Figure 1. In Figure 1 a plurality of mobile stations MS, are shown to communicate using radio signals 1, transmitted between the mobile stations MS and a plurality of base stations BS. The base stations are disposed in a spaced part relationship so as provide a radio coverage area which may be viewed as being made up from a number of cells 2. A cell 2, is defined as a geographical area within which radio communications may be effected with a base station as opposed to any of the other base stations in a mobile radio network. In Figure 1 the cells 2, formed for each of the three base stations BS illustrated are defined by the broken line 4. The mobile stations communicate data with each of the base stations BS, using radio signals 1, which are detected by the receive antenna 6. The base stations BS of the mobile radio network are coupled together via a mobile network infra-structure shown generally as a unit NET.

[0023] A characteristic of CDMA radio access techniques is that mobile stations MS, are arranged to communicate radio signals contemporaneously to the base stations BS, which operate to recover the data symbols communicated by the mobile stations by correlating the received radio signals with respect to a user specific spreading code. Data is communicated between the base station BS and mobile stations MS by modulating the data with a user specific spreading code and then

modulating the result onto a radio frequency carrier. At receivers in the respective base and mobile stations, the received radio signals are correlated with the user specific spreading sequence to the effect that the data symbols are recovered in spite of the presence of contemporaneously detected spread spectrum signals from other mobile and base stations as the case may be.

[0024] An illustration of the communication of CDMA signals between the mobile stations MS and one of the base stations BS shown in Figure 1 is illustrated in Figure 2 where parts also appearing in Figure 1 bear identical numerical designations. In Figure 2 a plurality of mobile stations MS are shown to communicate radio signals, contemporaneously with the base station BS. Multi-path propagation is illustrated in Figure 2 by the lines 8, 10, which comprise direct paths 8 and often indirect paths 10, which are reflected via objects such as buildings 12. As a result of the multi-path propagation of the radio signals, the data communicated by the radio signals will exhibit inter symbol interference in a case where a temporal difference in the time taken for the radio signals to reach the base station BS via at least two different paths is greater than a symbol period. As such the base station BS, must be provided with means to mitigate the effect of multi-path propagation.

[0025] As illustrated in Figure 2 the base station BS detects the received radio signals using the receive antennas 6, and communicates the detected radio signals to the front-end receiver 14. The front-end receiver 14 operates to down-convert the received radio signals and feeds the base band analogue signals to a data detector 16, via a conductor 18. The data detector 16, operates to recover the data communicated for at least one mobile station which is provided at an output conductor 20.

[0026] An example data detector 16 is illustrated in Figure 3 where parts also appearing in Figures 1 and 2 bear identical numerical designations. In Figure 3 the base band analogue signal is fed on the conductor 18 to an analogue-to-digital converter 20. The analogue-to-digital converter 20, operates with reference to a sampling clock 21 to sample the analogue signal at twice the chip-rate of the received spread spectrum radio signal. Coupled to an output of the analogue-to-digital converter 20, is a pre-equaliser 22, which in the present illustrative embodiment is a linear equaliser and therefore operates to convolve the base band sampled signal with tap coefficients $\overline{w}$ of the equaliser. The pre-equalised signals resulting at an output of the pre-equaliser 22, are fed to a decimator 24, which thereafter feeds the chip rate signals to each of a plurality of rake fingers 26 forming a rake detector. Also coupled to the output of the analogue-to-digital converter 20, is a pilot rake detector 30. The pilot rake detector 30, operates to correlate the received spread spectrum radio signals with reference to a pilot code which is locally generated within the pilot rake detector 30. The pilot rake detector 30, is arranged to search the received radio signals to the effect of detecting the most significant paths present in the received radio signals. In correspondence with the most significant paths a corresponding delay signal is generated and output on a conductor 31 to each of the rake fingers 26. The same delays are also fed to the receiver controller 28 via a conductor 33. The receiver controller 28 operates to adapt the equaliser coefficients of the pre-equaliser 22, and the channel impulse response coefficients which are used in the rake fingers 26, and fed to the rake fingers via a conductor 35.

[0027] For each symbol period, each of the rake fingers operates to convolve a locally generated version of a spreading code used to spread the spectrum of the received radio signals with an impulse response of the communications channel. That is to say the impulse response of the communications channel experienced by the received signals at the output of the preequaliser 22. The reference is time shifted according to the value communicated by the pilot rake via conductor 31, and then the time shifted reference correlated with respect to the received signals, integrated, and the integral then multiplied with the estimated tap coefficient communicated via the conductor 35, to generate an estimate of the data symbol for each rake finger. The estimated symbols are combined by a combiner 32 to generate an overall soft decision estimate of the detected data symbol which is fed to a threshold device 34, which operates to generate a hard decision of the data symbol or to slice the data symbol so as provide the final estimate of the data symbol.

[0028] As will be appreciated by those skilled in the art the rake fingers 26, the rake pilot 30, the analogue-to-digital converter 20, the combiner 32 and the slicer 34 substantially correspond to a conventional rake receiver. However the embodiment of the present invention is characterised by the pre-equaliser 22, which in the present embodiment is a linear pre-equaliser which is adapted under the control of the receiver controller 28.

[0029] In order to facilitate an explanation of the operation of the data detector 18, a schematic block diagram of the receiver controller 28, is provided in more detail in Figure 4 where parts also appearing in Figure 3 bear identical numerical designations. As shown in Figure 3 the signal at the output of the pre-equaliser is fed back to the receiver controller 28, via a conductor 37 as is shown in Figure 4.

[0030] The receiver controller 28, shown in Figure 4 comprises an initiator 36, fed with data from a data store 38. The initiator 36, provides initial estimates of the channel impulse response coefficients $\overline{w}_{init}$ and an initial estimate of the equaliser coefficients $\overline{v}_{init}$. These are fed to a adaptation processor 40, via two conductors 41, 42. The adaptation processor 40, operates to adapt the equaliser coefficients fed to the pre-equaliser via a conductor 39 and adapted channel impulse response coefficients fed to the respective rake finger via a conductor

35. The adaptation processor 40, operates to generate the pre-equaliser coefficients and the channel impulse response coefficients in accordance with an adaptation algorithm originally developed for adaptive antennas and disclosed in our co-pending UK patent application serial number GB 9804785.5 the contents of which are incorporated herein by reference. The adaptation processor calculates the update for the new pre-equaliser coefficients and the channel impulse response coefficients from an error signal e generated by an adder 42, fed on a first input with the signal from the output of the pre-equaliser 22, on conductor 37, and on a second input from an output of a channel convolver 44. The channel convolver 44, operates to convolve the channel impulse response estimate provided by the adaptation processor 40, with reference signal data stored in an associated data store 46 and fed to the channel convolver 44. At an output of the adder 42 the error signal e is formed which is fed to the adaptation processor 40, which operates to calculate a new estimate for the equaliser coefficients and the adapted coefficients of the channel impulse response estimate.

[0031] An explanation of the operation of the data detector in combination with the receiver controller 28 will now be described with reference to the example embodiment shown in Figures 3 and 4.

[0032] Generally the adaptive pre-equaliser operates to reduce the number of strong paths of residual inter symbol interference still present after the pre-equaliser output to a value within the range tolerable by the rake receiver. In effect the spread chip symbol stream is treated in the same way as an un-spread data symbol stream. Any type of pre-equaliser such as linear equaliser (LE) or decision-feedback (DFE) is appropriate. The adaptation processor 40, operates to adapt the equaliser coefficients and the channel impulse response coefficients during processing of a burst of radio signals. This adaptation process is relatively simple for a linear equaliser but is much more complicated for a decision feedback equaliser, where additional stability problems also arise. This is because, in the case of the decision feedback equaliser, in order to enable a feedback decision to be made, an unreliable tentative chip symbol decision must be performed before the normal de-spreading to data symbols or even decoding to take place. This requires re-coding data symbols and re-spreading to re-generate chip symbols to be fed back so as to minimise error propagation. Error propagation of the insecure tentative decision within the decision feedback equaliser is more likely to lead to errors in the following rake finger correlators. The general principle is illustrated by the exemplary embodiment of the invention given in Figure 3 and 4, in which a linear fractional-spaced equaliser is used as the pre-equaliser 22. It is well known that a fractional spaced equalisers is superior to a chip or T-spaced equalisers.

[0033] A particular advantage of the embodiment of the invention, is that separate chip timing synchronisation is not required because the linear equaliser also acts as an interpolation filter adjusting delays to facilitate detection of the data by the subsequent rake correlators. As such synchronisation is achieved not only to the chip rate but also to the symbol rate without requiring any further symbol synchronisation apparatus. However, some form of coarse chip rate synchronisation is required to avoid sampling frequency drifts in case of time-continuous transmission. In case of burst-wise transmission coarse timing synchronisation once per slot is sufficient.

[0034] The matched filter is a linear pre-equaliser applied to the received spread signal in order to generate the soft-decision chip symbol signal which ideally has no inter symbol interference from the channel or the transmit and receiver filters. However, such a pure linear equalisation can provoke drastic noise enhancement. Therefore, strong paths are not equalised but the associated inter symbol interference remains after pre-equalisation although inter symbol interference as a result of transmit and receiver filters is substantially cancelled. Thus, the remaining inter symbol interference is a series of dirac pulses temporally positioned at respective delays, which are estimated by the pilot rake 30. A maximum of N paths is not equalised if their power exceeds a certain proportion of the overall power. The delay resolution of the remaining paths is equal to the chip rate in consequence of decimation at the equaliser output, which is effected by the decimation filter 24. A model tap coefficient for every strong path is adapted together with the linear pre-equaliser coefficients. This process is described in the following paragraphs.

[0035] The adaptation processor 40, is used to track the channel coefficients and also used to track the pre-equaliser coefficients during each burst of radio signals. As an example the least mean squares algorithm is used although, as will be appreciated, this is only one example of a number of alternative ways of adapting the coefficients.

[0036] The task of adapting the equaliser coefficients is added to the tasks of the channel model coefficients adaptation, which is effected by the adaptation processor 40. As the adaptive pre-equaliser can also correct time shifts additional interpolation or timing synchronisation is not required.

[0037] The pre-equaliser coefficients are initialised to a value $\overline{v}_{init}$, by the initiator 36. This can be effected in various ways, such as, for example, by a least squares estimator based on the pilot data transmitted with the received radio signals. The channel impulse response is estimated by the initiator 36, and thus the model filter are initialized to a value $\overline{w}_{init}$, the estimated channel impulse response provided by a least squares estimator (also based on the pilot data) which is assigned to W whereas the new factor R is initialized by 1. The adaptation processor 40, operates in accordance with the process described with respect to adaptive antennas in the above referenced co-pending UK patent application

GB 9804785.5. The process was originally developed for adaptive antennas, but is applied here to adaptive filtering or equalisation. The pre-equaliser is also provided with an initial set of tap coefficients $\bar{v}_{init}$.

[0038] Introducing a vector to describe the time-shifted versions of the input signal g within the pre-equaliser 22, an error signal e generated by the adder 42, within the receiver controller 28, can be written as given in equation (1):

$$e = \bar{g}\bar{v} - R\bar{W}\bar{x} \qquad (1)$$

[0039] The adaptation process can be used for initialisation by treating the (time-shifted) input signal vector like the (space diversity) input signal vector $\bar{g}$ and the pre-equaliser coefficient vector $\bar{v}$ like the antenna coefficient vector $\bar{a}$. The additional dimension of time delivers a matrix description as presented in equation (2):

$$\bar{e} = \bar{G}\bar{v} - \bar{X}\bar{w} \qquad (2)$$

[0040] Generation of the initial set of equaliser and channel model coefficients is effected jointly by the initiator 36, and is arranged to be substantially optimum. Again a description of this optimisation process is provided in our co-pending patent UK application 9804785.5, but for adapting antenna coefficients as opposed to adapting the pre-equaliser coefficients as in the present case. The initialisation is effected by jointly optimising the pre-equaliser coefficients (instead of antenna coefficients) and the channel model coefficients using a pre-determined data sequence transmitted with the spread spectrum radio signals, which are known to the receiver. The pre-determined data sequence is contained in the data store 38, and is fed to the initiator 36, as shown in Figure 4. The generation of optimum values of the pre-equaliser and channel model coefficients is furthermore effected under the condition that the first channel model tap has a value of unity. This is effected by the constant '1' shown in Figure 4, as applied to input conductor 48 of the adaptation calculator 40.

[0041] The ideal condition for optimum adaptation that can only be fulfilled approximately is given by the matrix equation (3):

$$[\bar{G} - \bar{X}]\begin{bmatrix}\bar{v}\\ \bar{w}\end{bmatrix} = 0 \qquad (3)$$

[0042] Equation (3) can be rewritten by separating the first column $\bar{x}_0$ of $\bar{X}$ from the remainder $\bar{X}_S$ and the first tap w_0 from the remainder $\bar{w}_S$ as expressed in equation (4):

$$[\bar{G} - \bar{x}_0 - \bar{X}_S]\begin{bmatrix} \\ w_0\\ \bar{w}_S\end{bmatrix} = 0 \qquad (4)$$

[0043] Transferring the middle term in the matrix product to the right-hand side and obeying the constraint $w_0 = 1$, delivers an optimisation equation (5):

$$[\bar{G} - \bar{X}_S]\begin{bmatrix}\bar{v}\\ \bar{w}_S\end{bmatrix} = \bar{x}_0 \qquad (5)$$

[0044] Equation (5) has a solution given by equation (6):

$$\begin{bmatrix}\bar{v}\\ \bar{w}_S\end{bmatrix} = [\bar{G} - \bar{X}_S]^{+}\bar{x}_0 \qquad (6)$$

[0045] Here the operator $^{+}$ denotes the Moore-Penrose-inverse, $\bar{w}_S$ the shortened model tap weight vector without the first tap, $\bar{X}_S$ the shortened symbol matrix which is the remainder of the matrix $\bar{X}$ after the removal of the first column $\bar{x}_0$. Finally, the pre-equaliser and channel coefficients must be scaled according to different constraints, to the effect that for example $|\bar{w}|^2 = 1$ for the adaptation algorithm instead of the constraint $w_0 = 1$.

[0046] Synchronisation to the chips of the radio signal is determined by the initiator 36, using the pilot rake detector 30. Coarse timing synchronisation provided by the pilot rake detector 30, can be followed by a fine timing synchronisation by repeating the procedure for several timings close to the coarse timing already obtained from the pilot rake. Fine timing synchronisation in this way delivers the pre-equaliser and channel model coefficients required for initialisation.

[0047] Convergence properties are not as important since the adaptation is used for tracking only. As will be appreciated, simpler timing synchronisation strategies are to be applied, and synchronisation from scratch can be considered.

[0048] The adaptation process which uses a common factor for all tap weights replaces the tap coefficients w by a product RW and introduces a penalty term to control the amplitude of R. The new version with common factor R, is derived from the adaptation in accordance with a principle of deepest decent for a special case of the known (leaky) Least Mean Squares (LMS) algorithm. The example adaptation algorithm introduced here is an add-on to the (leaky) LMS algorithm with a common factor for all tap weights. Once more, the channel tap coefficients w are split into the product of the factors R (rotator, describing a common variation of all taps) and W (multiplicative offset describing individual tap variations). For the derivation the extended tap vector is augmented by the additional component $\bar{v}$ and a penalty term is introduced into the cost function to keep the amplitudes of R and $\bar{W}$ close to 1. Re-deriving using the original LMS algorithm will then yield the new version with common factor R and, in additional the pre-equaliser coefficient adaptation. In the following this is shown for the LMS as an example that is derived from the principle of steepest descent.

[0049] Both the pre-equaliser and channel impulse response coefficients are incremented from previous estimates by certain amounts determined by the error signal e, the symbol vector $\bar{x}$ and the adaptation step size μ according to the well-known LMS algorithm. For improved adaptation the tap coefficient vector $\bar{w}$ is represented as the product of a scalar factor R and a mul-

tiplicative offset vector $\bar{W}$. By straightforwardly re-deriving the LMS equation from the principle of steepest descent and replacing the tap coefficient vector $\bar{w}$ by the product $R\bar{W}$ and using an extended tap vector, according to equation (6), delivers the LMS equations for pre-equaliser and channel coefficient estimation, bearing in mind that t denotes the time sample and $\bar{x}$ the hard decision vector.

$$\bar{w}_E = \begin{bmatrix} \bar{v} \\ \bar{W} \\ R \end{bmatrix} \qquad (6)$$

[0050] Separate step sizes are also introduced for all taps in order to allow the adaptation to be slowed down or deactivated for weaker taps. With the operator • denoting element-by-element multiplication, therefore, the well-known leaky LMS equation with a leakage factor $L = L_R L_W$, with for example $L_R = L_W = 1 - 1 \textit{least significant bit}$, for improved stability and to assure desired constraints, adaptation of the channel impulse response coefficients is expressed as given in equation (7):

$$\bar{w}_t = L\bar{w}_{t-1} + \mu e_{t-1}\bar{x}_{t-1} \qquad (7)$$

[0051] Applying this to the adaptation of the pre-equaliser coefficients, leads to equation (8), equation (9) for the individual multiplicative tap offsets, and equation (10) for the taps rotator with a scalar product:

$$\bar{v} = \bar{L}_v \cdot \bar{v} - \bar{\mu}_v \cdot e\bar{g}^* \qquad (8)$$

$$\bar{W}_t = L_W\bar{W}_{t-1} + \bar{\mu} \cdot e_{t-1}R^*{}_{t-1}\bar{x}_{t-1} \qquad (9)$$

$$R_t = L_R R_{t-1} + \mu_R e_{t-1}\bar{W}_{t-1}{}^*\bar{x}_{t-1} \qquad (10)$$

[0052] If a penalty term is introduced to keep the absolute values of R and $\bar{W}$ close to 1, equation (10) must be modified slightly by changing the normal value L_R (for the "normal" case that the absolute value is above 1) to $2 - L_R$ and likewise the normal value $\bar{L}_W$ for the "normal" case that the absolute value is above 1, to $2 - \bar{L}_W$, if the respective absolute value is below 1. Alternatively, a penalty term can be used to keep the absolute values of R and $\bar{v}$ close to 1. The rotator update equation must then be modified slightly by changing L_R to $2 - L_R$ and $\bar{L}_v$ to $2 - \bar{L}_v$ if the respective absolute value is below 1. In the latter case the absolute value of the pre-equaliser tap weight vector is constrained rather than the absolute value of the model tap weight vector.

[0053] The algorithm can be configured by the following parameters: Adaptation step sizes (known from LMS theory): $\bar{\mu}_v$ controls the estimation of the pre-equaliser coefficients $\bar{v}$, μ_R the estimation of R and $\bar{\mu}$ the estimation of (the vector) $\bar{W}$. The parameters can be configured from outside on a call-by-call basis individually for maximum flexibility.

[0054] The leakage factors $\bar{L}_v$, $\bar{L}_W$ and L_R can be switched off, if desired for faster tracking at the expense of a stability reduction and constraint violation which should pose no problem, however, for signals with short bursts.

[0055] During the training sequence known training symbols are used for adaptation instead of the detected symbols allowing a fast adaptation from scratch within, for example, sixteen symbols. During the data sequence the adaptation must be slowed down to a reasonable degree in the case of very fast adaptation from scratch.

1. Deactivated adaptation: $\bar{\mu}_v = 0$, $\bar{\mu} = 0$, $\mu_R = 0$
The pre-equaliser coefficients remain unchanged during each burst and the equaliser performs like an ordinary non-adaptive equaliser. This is achieved by switching off both the leakage and the update of the pre-equaliser and channel coefficients. If this mode is also chosen during training with the mid-amble, the tap coefficients must be provided by the initial value estimator in this special case.

2. Traditional LMS operation mode for channel coefficients only: $\bar{\mu}_v = 0$, $\bar{\mu} = 2^{-5}$, $\mu_R = 0$
The pre-equaliser coefficients remain unchanged during each burst of radio signals and the overall channel coefficients used in the rake for maximum ratio combining of paths are estimated according to the traditional LMS adaptation. This mode is well-known from theory, including the disturbing effects, convergence and stability. In order to allow all taps to follow the rapid changes, all step sizes have to be set rather high so that noise amplification becomes visible. Faster adaptation is possible but at the expense of large noise amplification. From the theory of the LMS algorithm it is well known that step sizes larger than the reciprocal of the number of taps (i.e number of channel coefficients) lead to instabilities.

3. Traditional LMS operation mode for pre-equaliser only: $\bar{\mu}_v = 2^{-5}$, $\bar{\mu} = 0$, $\mu_R = 0$
The channel model coefficients remain unchanged during each burst of radio signals and the pre-equaliser coefficients are adapted according to the traditional LMS algorithm. In order to allow all the pre-equaliser coefficients to follow rapid changes, all step sizes have to be set rather high so that noise amplification becomes visible. Faster adaptation is possible but at the expense of large noise amplification. From the theory of the LMS algorithm it is well known that step sizes larger than the reciprocal of the number of taps (i.e number of pre-equaliser coefficients) lead to instabilities.

4. Traditional LMS operation mode: $\bar{\mu}_v = 2^{-6}$, $\bar{\mu} = 2^{-6}$, $\mu_R = 0$
Both the pre-equaliser and the channel model coef-

ficients are adapted according to the traditional LMS algorithm. As a first guess it is envisaged that, for example, doubling the number of coefficients to be adapted by additional adaptation of the pre-equaliser coefficients the adaptation step sizes must be halved for similar stability and noise amplification. In order to allow all taps to follow rapid changes all step sizes have to be set rather high so that noise amplification becomes visible.

5. Normal operation mode: $\overline{\mu}_V = 2^{-5}$, $\overline{\mu} = 2^{-6}$, $\mu_R = 2^{-3}$

The rotator R takes advantage of the fact that a considerable amount of tap variations is common to all taps as it is due to down link effects leading to a carrier frequency error and due to the absence of explicit carrier recovery. If the rotator adapts fast enough the individual taps can be adapted slower than in the case of traditional LMS adaptation without a rotator. Without pre-equaliser coefficient adaptation the rotator contributes to the noise amplification with roughly the same amount as each individual tap on its own. Use of the rotator allows a reduction in all individual step sizes so that the effect of noise amplification is reduced drastically. In consequence, no significant increase in error rates after the channel decoder arises even for poor signal to noise rarios. Extrapolating these results to the case with pre-equaliser coefficient adaptation, the old adaptation step sizes for the individual taps are halved to allow the original value for the adaptation step size of the pre-equaliser coefficients.

6. Fast operation mode: $\overline{\mu}_V = 2^{-4}$, $\overline{\mu} = 2^{-5}$, $\mu_R = 2^{-2}$
Although error rates increase noticeable for stationary channels, fast variations are tracked better than in the normal operation mode. Obviously, the signal to noise ratio or carrier to interference ratio performance is slightly degraded.

7. Very Fast operation mode: $\overline{\mu}_V = 2^{-3}$, $\overline{\mu} = 2^{-4}$, $\mu_R = 2^{-1}$
The operation range approaches the edge of stability and performance degradation therefore becomes significant for channels that do not vary very fast. Yet, even very fast variations can be tracked at the expense of significantly worsened signal to noise ratio or carrier to interference ratio performance.

8. Pre-equaliser Element or Tap Switch-Off mode: $\overline{\mu}_V = 2^{-3}$, $\overline{\mu} = 0$, $\mu_R = 2^{-2}$
If desired the adaptation can be switched off for some model or pre-equaliser taps so as to allow faster adaptation of the remaining taps with constant signal to noise ratio or carrier to interference ratio performance. This is achieved by the separate configuration of all adaptation step sizes for each tap. The adaptation of missing pre-equaliser elements should be switched off to avoid unnecessary noise amplification. Obviously, this special-case mode relies on the individual surroundings of the base station for switching off channel taps. The taps can be switched on a call-by-call basis if desired.

9. Rotator Mode: $\overline{\mu}_V = 2^{-3}$, $\overline{\mu} = 0$, $\mu_R = 2^{-2}$
If desired the individual adaptation of tap coefficient offsets can be switched off so as to allow faster adaptation of the rotator and the pre-equaliser coefficients with constant signal to noise ratio or carrier to interference ratio performance. Obviously, this special-case mode relies on the individual surroundings of the base station. Specifically, a single dominating path (that may be accomplished by directional pre-equalisers) will make multi-path propagation negligible and allow parallel adaptation of all taps.

[0056] As will be appreciated by those skilled in the art various modifications may be made to the embodiment herein before described without departing from the scope of the present invention. In particular various techniques for adapting the coefficients of the pre-equaliser can be envisaged and various types of equaliser such as a linear, decision feedback or maximum likelihood type equaliser can be used as a pre-equaliser for the rake fingers. Furthermore the present invention finds application in both Wide band CDMA or Time Division CDMA as well as other modulation schemes.

Claims

1. A receiver for recovering data from received spread spectrum radio signals, said receiver comprising

   - filter means (22, 28) operating to filter said received radio signals with respect to an impulse response adapted to said radio signals, and
   - a symbol estimation means (26, 30, 32, 34) coupled to said filter means (22, 24) and arranged to estimate said data by de-spreading said spread spectrum radio signals with respect to a corresponding spreading code consequent upon the output of the matched filter means (22, 24).

2. A receiver as claimed in Claim 1, wherein said filter means (22, 24) is an equaliser means (22), which operates to mitigate at least some inter symbol interference present in the radio signals.

3. A receiver as claimed in Claim 1 or 2, wherein said equaliser means (22) operates to condition inter-symbol interference to the effect that inter-symbol

interference remaining in said pre-equalised spread spectrum radio signals corresponds to at least one propagation path of said spread spectrum radio signals.

4. A receiver as claimed in Claims 2 or 3, wherein said equaliser means (22) is arranged to convolve said received radio signals with a plurality of equaliser coefficients.

5. A receiver as claimed in Claim 4, and further including a receiver controller (28) which operates to adapt said equaliser coefficients consequent upon an error signal derived from the received radio signals.

6. A receiver as claimed in any preceding claim, wherein said data symbol estimator means (26, 30, 32, 34) operates to detect said data symbols from said spreading code in combination with an estimate of an impulse response of a communications channel through which the received signals have passed, which impulse response estimate comprises a plurality of impulse response coefficients which are adapted by said data processor.

7. A receiver as claimed in any preceding Claim, wherein said data symbol estimator means (26, 30, 32, 34) is a rake detector means having at least one rake finger (26) arranged to correlate said sampled base band signal with respect to said spreading code at a delay determined from the channel impulse response estimate at relative temporal displacements corresponding to said at least one propagation path conditioned by said equaliser means and scaled by a corresponding impulse response coefficient.

8. A receiver as claimed in Claim 7, wherein the radio signals include a pre-determined signal formed with a pilot spreading code, and said rake detector (26, 30, 32, 34) is further provided with a pilot rake means (30) which operates to identify said at least one propagation path, by comparing said received radio signals with said pilot spreading code, and consequent upon said identified at least one path, allocate said at least one rake finger (26) to said corresponding at least one path.

9. A receiver as claimed in any of claims 2 to 8, wherein said equaliser means (22) is a linear equaliser or a decision feedback equaliser or the like.

10. A receiver as claimed in any preceding claim, and further including means for decimating said spread spectrum signals (24) coupled between said equaliser means (22) and said rake detector means (26, 30, 32, 34), and arranged to form said spread spectrum signals with one sample per chip.

11. A method of recovering data from received spread spectrum radio signals, said method comprising the steps of,

- filtering said spread spectrum radio signals with respect to an impulse response adapted to the spread spectrum radio signals, and
- detecting said data from the matched filtered signals in combination with a spreading code used to spread the spectrum of said radio signals.

12. A method of recovering data as claimed in Claim 11, wherein the step of filtering said received radio signals, comprises the step of

- equalising said spread spectrum signals using an equaliser means to the effect of mitigating at least some inter symbol interference present in said signals.

13. A method of recovering data as claimed in Claim 11 or 12, wherein the step of matched filtering said received radio signals further includes the step of

- conditioning said spread spectrum signals to the effect that said inter-symbol interference remaining in said pre-equalised spread spectrum signals corresponds to at least one selected propagation path of said spread spectrum radio signals.

14. A method of recovering data as claimed in Claim 12 or 13, wherein the step of equalising said spread spectrum signals, comprises the step of

- combining said sampled radio signal with a plurality of equaliser coefficients.

15. A method of recovering data as claimed in Claim 14, and further including the steps of,

- determining an error signal from said detected radio signals; and
- adapting said equaliser coefficients to the effect of minimising the error signal.

16. A method of recovering data as claimed in Claim 15, wherein the step of estimating said data symbols from said matched filtered signals, comprises the step of;

- estimating an impulse response of a channel through which the received signals have passed; and
- de-spreading said matched filtered signals with

a spreading code with which the spread spectrum signals were generated, in correspondence with components of the channel impulse response.

17. A method of recovering data as claimed in Claim 16, wherein the steps of de-spreading said matched filtered signals comprises the steps of

- correlating said matched filtered signals with respect to said spreading code at a delay determined from a component of said channel impulse response, scaled by a corresponding coefficient of the channel impulse response estimate.

18. A method of recovering data as claimed in Claim 17, wherein the channel impulse response coefficients are adapted with respect to time in accordance with a time at which the data symbols are detected.

19. A communications apparatus having a receiver as claimed in any preceding claim.

20. A receiver as herein before described with reference to the accompanying drawings.

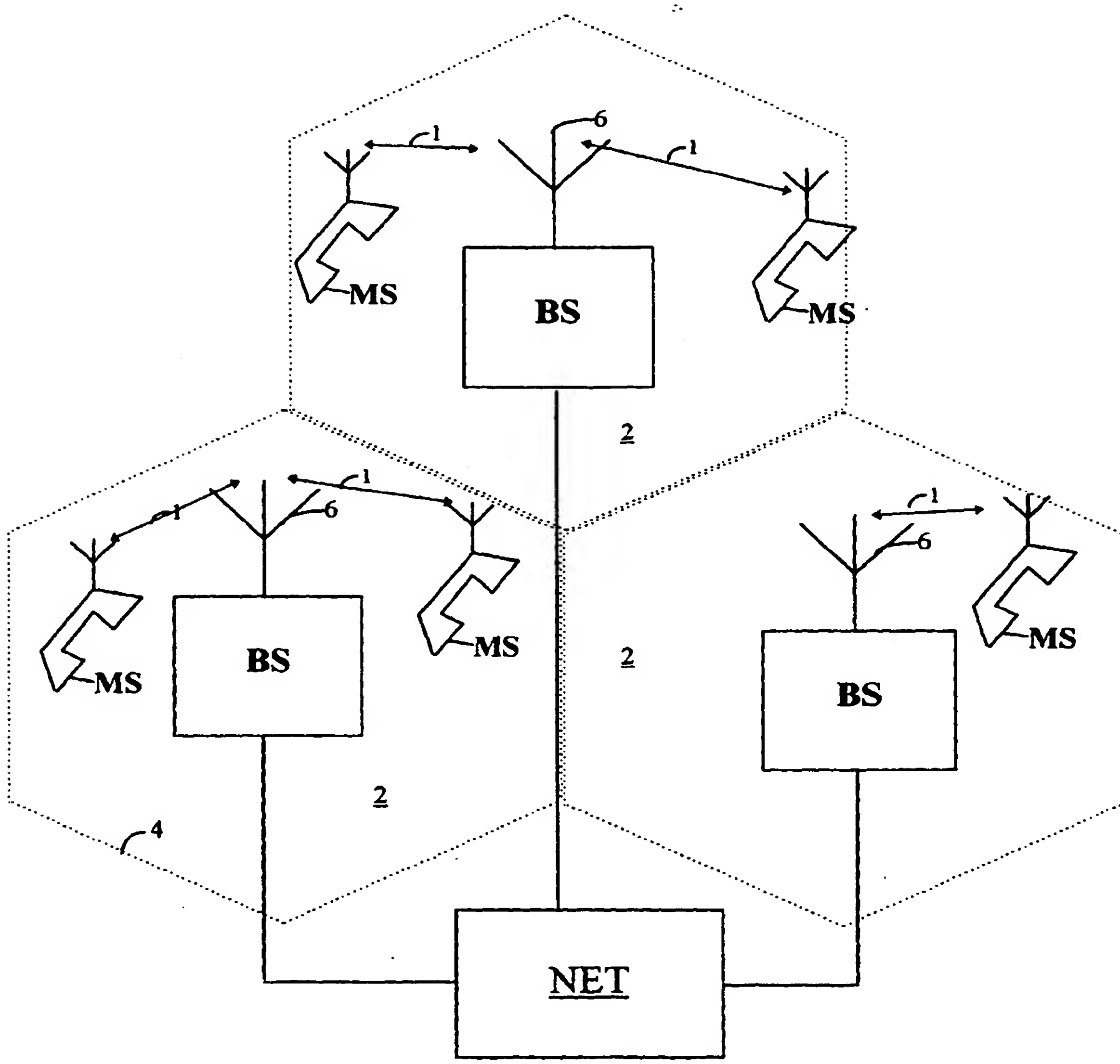


Fig. 1

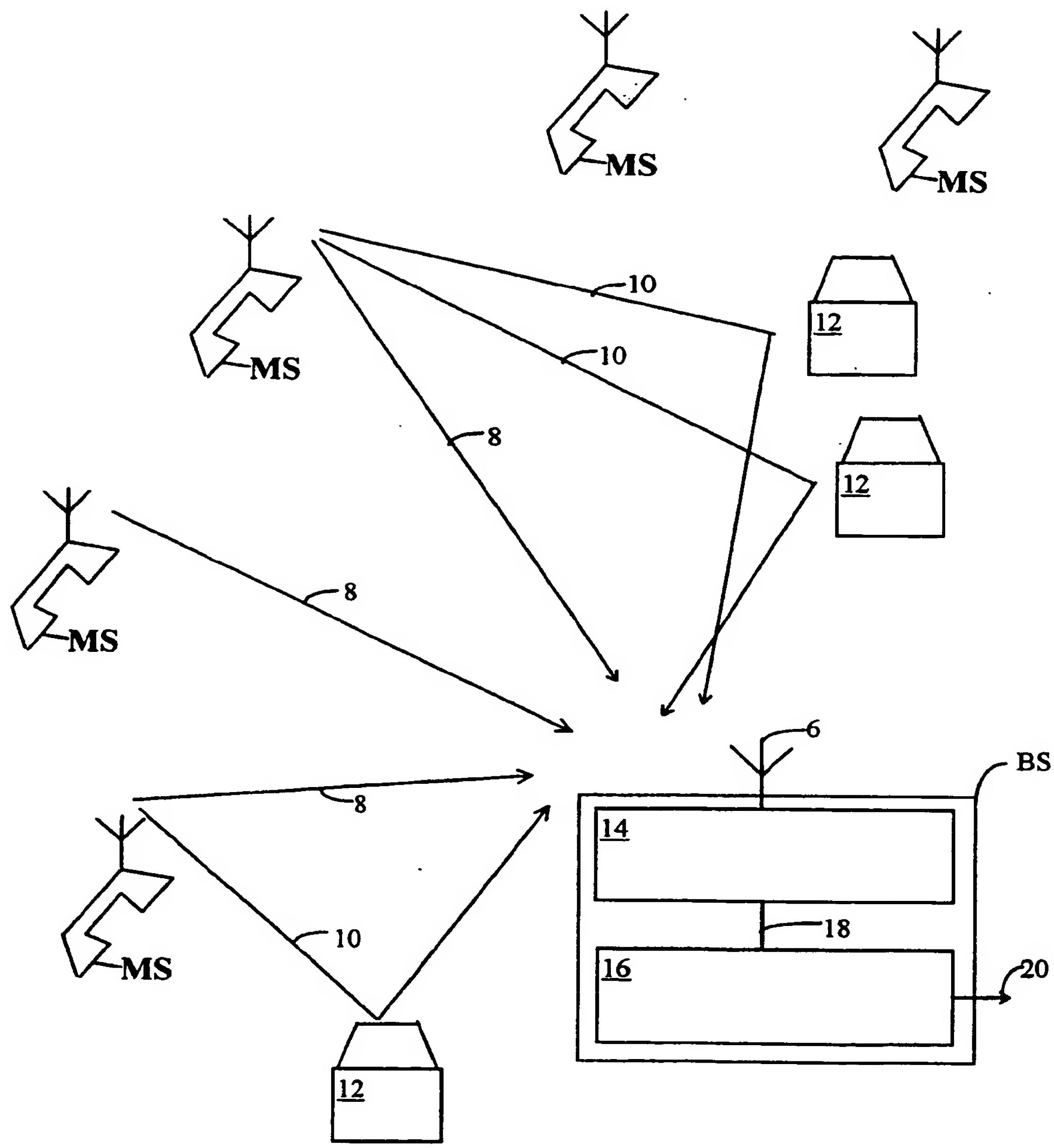


Fig. 2

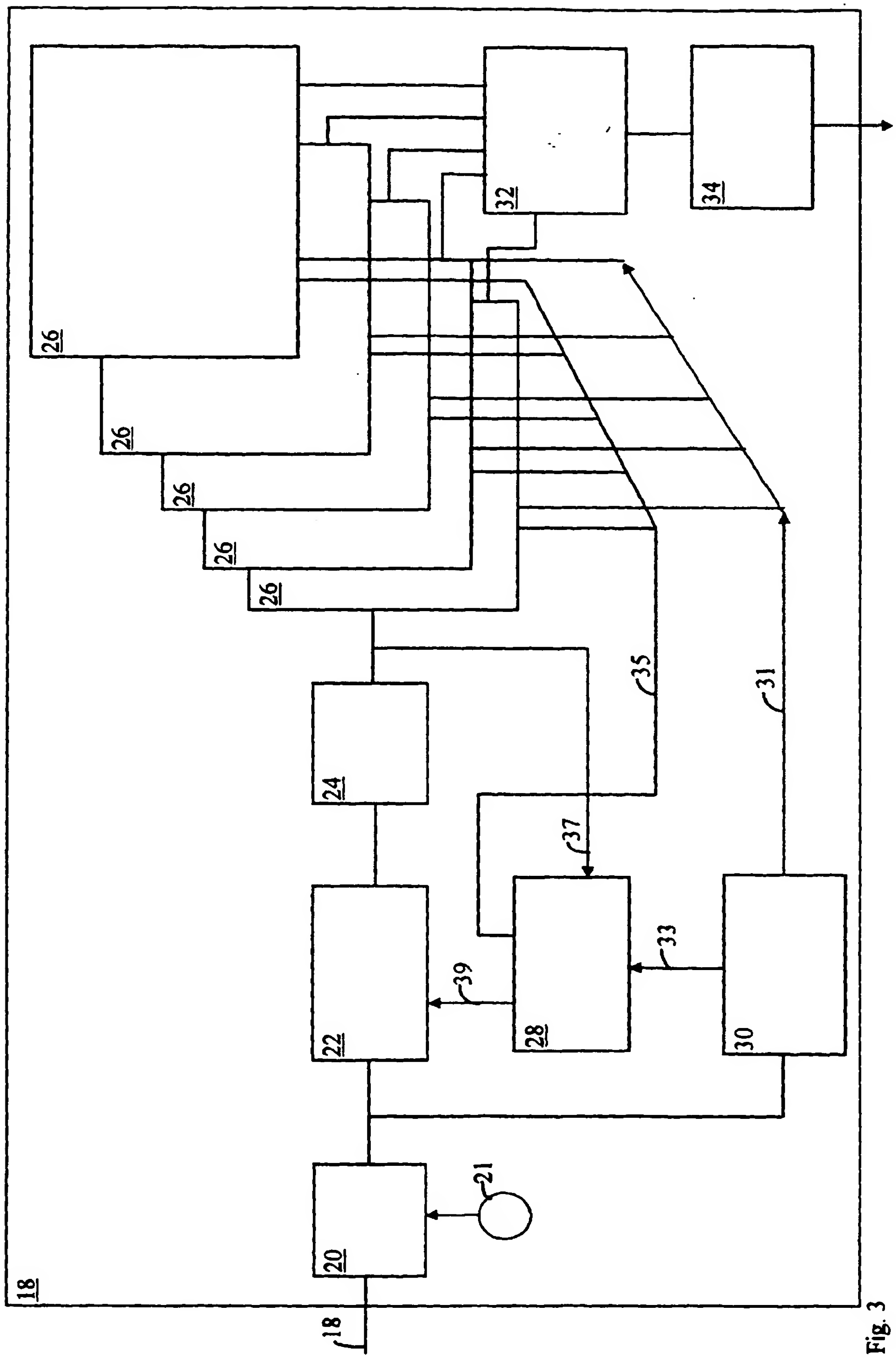
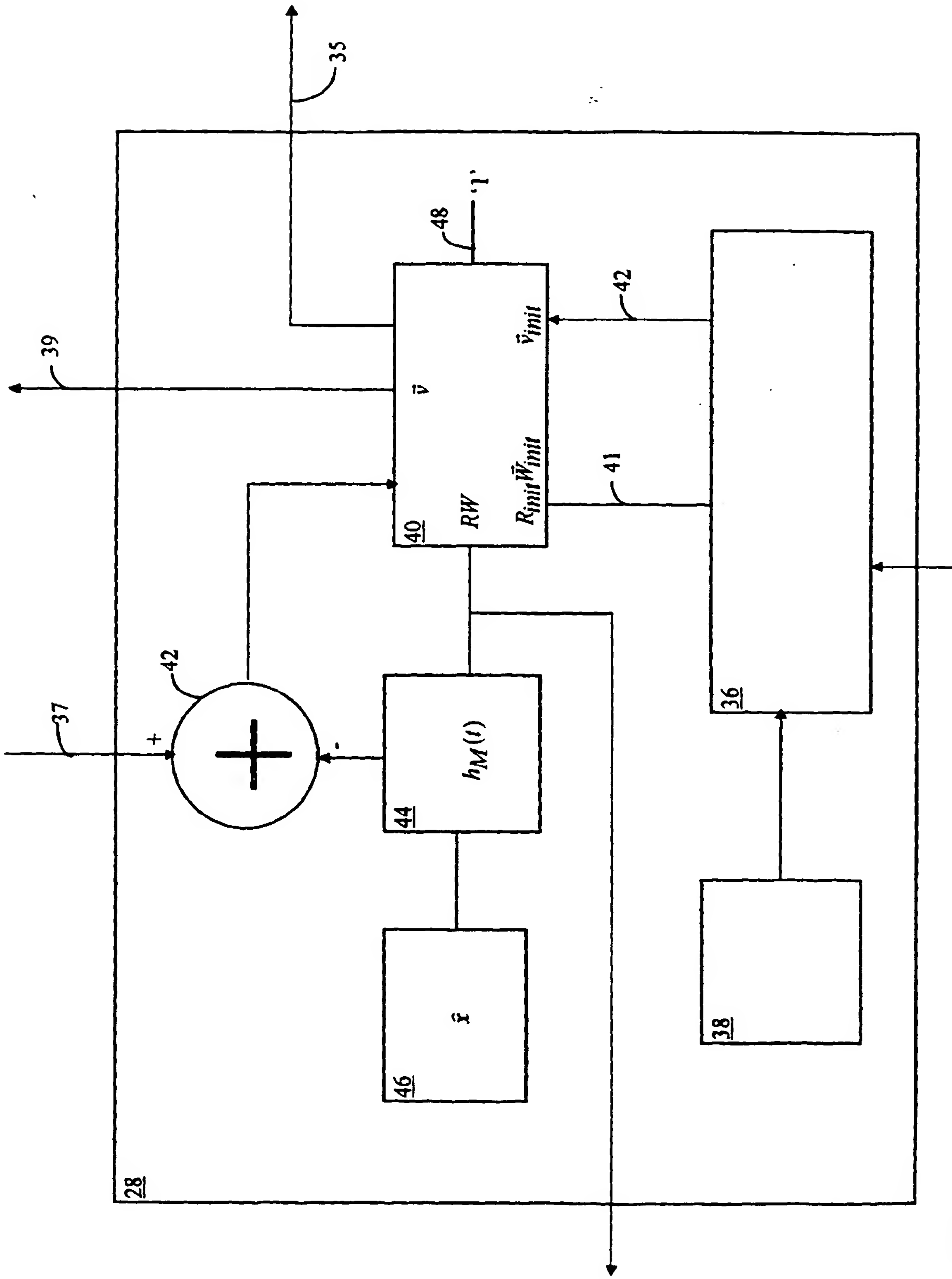


Fig. 3


35
39
48
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42
$\vec{v}_{init}$
$\vec{v}$
$R_{init}\vec{W}_{init}$
RW
40
41
37
+
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42
$h_M(t)$
44
36
46
38
28

Fig. 4

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 98 11 5646

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	US 5 757 853 A (TSUJIMOTO ICHIRO) 26 May 1998	1-4,6-8, 11-14. 16-20	H04B1/707
A	* column 2, line 29 - line 43; figure 1 * * column 6, line 1 - line 41; figure 4 * * column 7, line 60 - column 8, line 19 * ---	5,8,10, 15	
A	PATENT ABSTRACTS OF JAPAN vol. 016, no. 108, 17 March 1992 & JP 03 283826 A (NEC CORP), 13 December 1991 * abstract * -----	1-20	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)
H04B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	22 January 1999	Harris, E

CATEGORY OF CITED DOCUMENTS

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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 98 11 5646

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22-01-1999

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5757853 A	26-05-1998	JP 2705623 B	28-01-1998
		JP 8265236 A	11-10-1996
		FR 2732173 A	27-09-1996

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82